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AUTHORITY

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Deterioration of Wood By Marine Boring Organisms ★

By H. HOCHMAN

Figure 1—*Teredo* larvae.

Figure 2—Adult *Teredo* containing larvae.

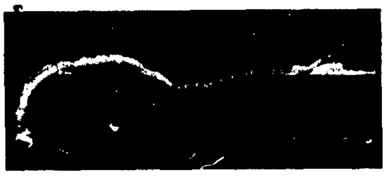

Figure 3—Adult *Teredo* and *Bankia*.

Figure 4—*Limnoria tripunctata*, ventral view.

Introduction

THE DESTRUCTION, by marine boring organisms, of wooden structures exposed to the sea has plagued man since the dawn of history. Although many devices have been employed to combat their destructive activities, marine boring organisms cause an estimated 50 million dollars worth of damage each year to water front structures along the coasts of the United States. In addition to these costs is the inconvenience that occurs when piers and ships are removed from service during their reconstruction period.

The rate at which untreated timbers can be destroyed by marine boring organisms can be illustrated by a situation that occurred in Hawaii and was reported by Dr. C. H. Edmondson of the Bernice P. Bishop Museum.[1]

In the process of laying an outfall sewer off Sand Island in Hawaii, a long trestle was constructed of untreated Douglas fir from which the heavy equipment required to handle the huge concrete pipe was to operate. Danger from marine borers was realized, but since the project was to be completed in eight months, the construction company considered the use of treated structural timbers any unnecessary expense. In 70 days, sections of the trestle collapsed, plunging considerable heavy equipment including diesel engines into the sea. The equipment was recovered, but valuable time was lost in removing what was left of the trestle and completing the job from floating barges.

Natural Resistance of Wood

All wood species tested for resistance to marine boring organisms have been damaged by these organisms. The rate of damage, however, varies considerably for different species and in different harbors.

Douglas fir is readily attacked by marine borers[2] as are most native American wood species used for marine piling. There are a few woods, however, that have gained reputations for resistance to marine borers. Among these are the South and Central American woods Greenheart and Angelique and the Australian turpentine wood.

Although resistant woods may withstand borer attack for long periods of time in some harbors, they are readily attacked in other harbors. For example, Greenheart piles rated as being in good condition after 80 years in the harbor of Liverpool, England, were attacked in four years at Salem, England, and failed in Java, India, in five to ten years.[3,4]

In addition to the variable resistance to marine borers offered by resistant woods in various harbors, the same species of wood grown on different soils may differ considerably in both composition and resistance. Turpentine wood, *Syncarpia laurifolia*, is used extensively as a pile timber in Australia. In exposure tests in Honolulu harbor, Australian grown turpentine wood was lightly attacked by *Teredo* and showed moderate superficial action by *Limnoria* after four years.[5] Blocks of the same species grown in Hawaii were often badly damaged in five months. Chemical analysis showed the Australian grown wood to contain up to 1.25 percent silica; the maximum silica content of Hawaiian grown wood was

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Abstract

Most untreated woods are readily attacked by marine boring organisms. Some woods are naturally resistant to attack by some borer species and serve well in some harbors. Present standard wood preservative treatment, creosote or creosote-coal tar impregnation, is satisfactory in arctic and temperate waters but does not give long-term protection in tropical and sub-tropical waters. Although creosote prevents attack by the Teredine or shipworm type of marine borer and by two of the three species of *Limnoria* present in U. S. harbors, one species, *Limnoria tripunctata*, which thrives in warm waters, successfully attacks creosoted wood. Because many Navy waterfront structures are located in areas where early failure of creosoted wood occurs, the Bureau of Yards and Docks is investigating the marine borer problem. 3.3.3

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0.17 percent. The averages of a number of samples were 0.59 percent and 0.091 percent, respectively.

Some correlation seems to exist between the silica content of wood and its resistance to marine borers. Woods with a high silica content, with few exceptions, are more resistant than woods of low silica content.[4] To determine the effects of increasing the silica content of wood, southern yellow pine blocks were impregnated with silica. The borer resistance was increased. Untreated blocks were destroyed in three to six months while panels impregnated to a high silica content were only lightly damaged after two years. Unfortunately, although the resistance to wood borers had increased, the resultant product appeared to be suitable for rock boring pholads. A number of panels were severely damaged by these animals.

Some resistant woods do not have a high silica content. Examples of such woods are Greenheart and *Lignum vitae*. The resistance of some of these woods has been attributed to their alkaloid content[7] and the author's laboratory is now engaged in isolating and identifying the alkaloids of Greenheart.

It should be noted, however, that in no case have woods of high silica content been low in borer resistance although a few woods of low silica content may be resistant because of their alkaloid content or for other reasons.

It can be seen from the preceding discussion that naturally resistant woods can be used for waterfront structures in some harbors, but the number of harbors in which they can be used without preliminary investigation is comparatively small.

The term marine borer has been generally used to include those marine invertebrates which drill into and consequently damage timber and other solid objects in salt water. Other destructive marine borers may cause considerable economic loss to industry, such as the boring sponge which perforates the shells of oysters. In this paper, the definition will be restricted to those marine invertebrates which attack wooden structures.

Marine Borer Groups

The animal organisms responsible for the biological deterioration of wooden marine structures are members of two main groups. The first group is composed of animals from the phylum *Mollusca*. In their larval stages, they are oyster or clam-like in appearance and metamorphose into worm-like animals as they bore into wood. Members of this phylum are responsible for the rapid destruction of timbers exposed in a marine environment. The particular genera involved are the *Teredo* and *Bankia* of the family *Teredinidae* and the pholad *Martesia*.

The second group of organisms is comprised mainly of species of the genus *Limnoria* and in some harbors by members of the genus *Sphaeroma*. They are shrimp-like in appearance, about ⅛-inch to ¼-inch long, and generally burrow just beneath the surface of the wood. These animals have been described as having the body of a shrimp and the head of a termite. They are responsible for the wood destruction readily visible on surface inspection of wood.

Life Cycles

The molluscan or teredine borers begin their existence as free-swimming larvae, shown in Figure 1. The two *Teredo* species, *Teredo navalis* and *Teredo diegensis*, found on the West Coast of the United States, are bisexual. Fertilization and development of the larvae occurs within the body of the animal, and the mature larvae are ejected into the sea through the excurrent siphon of the animal. At this stage the larvae of *Teredo diegensis*, the only species identified at Port Hueneme, are about 250 microns (0.01 inches) in diameter. They must attack wood within 48 hours or they lose their ability to bore successfully into wood. They crawl on the surface of the wood by means of an amoeboid projection called the foot until they find a place suitable for boring. Once an animal has bored into wood, its life cycle is completed in that piece of wood.

Four significant changes now take place: (1) A serrated projection develops at a 90-degree angle to the original shell hemispheres; (2) Siphons develop which permit the animal to pump sea water through its body; (3) The clear chitin shell of the larva starts to calcify; and (4) The animal begins to elongate (Figure 2) with the shell or boring end proceeding into the wood and the siphon end remaining at the original site of penetration.

The only *Bankia* species of any significance on the west coast of the United States is *Bankia setacea*, shown in Figure 3. Like all other members of this genus, and in contrast to some species of *Teredo*, adult animals eject sperm and eggs into the sea where fertilization takes place. Swimming [illegible] larvae are developed within a few hours. The larvae develop for about a month before they are ready to attack wood. After wood is attacked, the *Bankia* larvae metamorphose in a manner similar to that of the *Teredo*.

No *Martesia* are found in harbors of western United States, but these borers are found in Hawaii and other Pacific islands. These animals differ from the Teredine borers in only one major respect: the metamorphosis into a worm-like structure does not take place. As a result, the animals burrow just below the surface, enlarging the burrows as they grow.

The crustacean borers resemble a sow bug in appearance, Figure 4. The most common wood borers of this class are members of the genus *Limnoria*, also known as the gribble. The body of the animal is from ⅛-inch to ¼-inch in length and is about one-third as wide. Their seven pairs of legs have sharp, hooked claws which enable the animals to cling to wood and move freely on its surface. They burrow just below the surface of the wood and form a series of tunnels. Menzies[4] found that at a low population density there are only two animals in each tunnel, one male and one female, with the female in the blind end of the tunnel.

The female carries the eggs in a brood pouch on the underside of the body between two rows of legs. The number of eggs in a single brood is seldom less than six or more than seventeen. When hatched, the young differ only in size from the adult and are ready to bore at once. They begin to bore near the parent so that *Limnoria* infestation generally spreads from a center. Heavily infested wood may contain 300 to 400 animals of all ages per square inch.

Three *Limnoria* species are found along the western coast of North America.[8,9,10] They are shown in Figure 5. The species *Limnoria lignorum* is found from Alaskan waters as far south as Point Arena, California. Between Point Arena and Port Hueneme or Los Angeles, California, the predominant *Limnoria* species is *Limnoria quadripunctata*, and *Limnoria tripunctata* is the principal species in Los Angeles harbor and southward. The relationship between *Limnoria* species and water temperatures has been pointed out by Menzies. The *Limnoria lignorum* requires cold waters, *Limnoria tripunctata* requires warm waters with *Limnoria quadripunctata* requiring an intermediate temperature.

The largest crustacean known to damage wood is the *Sphaeroma*. While their burrows are much larger than those of *Limnoria*, the animals themselves are not as numerous nor as destructive. They are reported to exist along the Pacific Coast as far north as Alaska and have been found in test boards outside San Francisco Bay. They appear to prefer very soft wood and do not constitute a serious economic problem.

Examination of Damage

Examination of a cleaned block of ¼-inch laminated southern yellow pine that had been exposed in Hueneme harbor for eight months, Figure 6, shows little structural damage caused by marine boring organisms. Figure 7 is a magnified view of *Limnoria* in their burrows just below the surface of untreated wood.

Close examination of the block while it is still in the sea water, Figure 8, shows the siphons of the teredine borers projecting from the surface. This is the only evidence of the presence of the shipworm type of borer that is visible on surface inspection of the block. Even these, however, may not be seen unless the block has just been cleaned to remove fouling organisms.

Sawing the block into two parts, Figure 9, or separating the lamina, Figure 10, shows the severe structural damage which the shipworms have caused. The larger holes are caused by *Bankia setacea* which, in Hueneme harbor, can grow to a length of 10 to 12 inches in eight months. The smaller holes are caused by *Teredo* present in Hueneme harbor, where they seldom grow to lengths of more than 5 or 6 inches.

Methods of Treatment

Since man first recognized the shipworm problem, many remedies have been tried. The earliest means of combatting borers probably consisted of anchoring

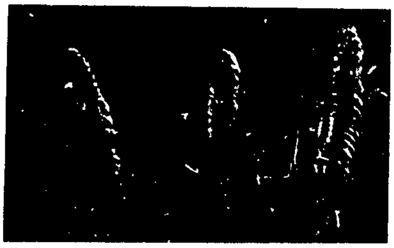

Figure 5—*Limnoria* species: *lignorum, tripunctata* and *quadripunctata*.

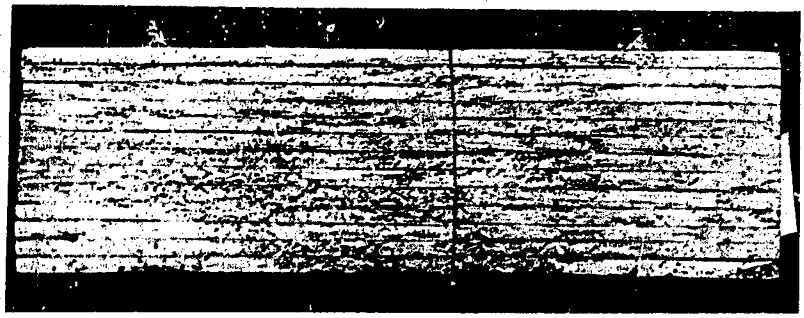

Figure 6—Exterior of laminated test block.

ships upstream from river estuaries. In addition to killing any shipworms that were in the wooden hulls, this procedure also caused fouling organisms to drop off of the sides and bottoms of the vessels. As ships traveled further and further from shore and were away from their harbors for longer periods of time, other procedures were inaugurated. These included such practices as applying brews and concoctions of many kinds, metal sheathing and scupper nailing. Some of these methods have persisted for many years. Fishermen in Iran, for example, still bring their fishing vessels out of the water periodically and apply a concoction prepared from local berries to the entire hull.

The most satisfactory method which has been developed for the preservation of wood in a marine environment is the practice of creosoting. In some harbors, especially the cold water harbors, creosoted timbers have lasted 30 years and more. In warmer harbors, however, creosoted pilings, just like some of the naturally resistant wods, do not last longer than 10 to 15 years. More recently the practice of incorporating coal tar into creosote has given protection for longer periods of time.

The incidence of early failure of creosoted timbers coincides to a considerable extent with the presence of *Limnoria tripunctata.* These animals apparently can live in the presence of high concentrations of creosote, as seen in Figure 11. As they erode away the creosoted surface, the lightly treated or untreated portions of the structure are exposed. The structure can be attacked now by the shipworm type of organism and is destroyed in a relatively short period of time. Any new treatment should, therefore, be aimed primarily at the *Limnoria* species of borer.

Admiral E. V. Dockweiler and Carrol M. Wakeman of the Los Angeles Harbor Department have allowed the author to present the following account of a pier in a *Limnoria* infested area of Los Angeles Harbor:

"In the year 1913, or the early part of 1914, a number of Douglas fir piles were driven in the wharf system at Berths 57-60, Los Angeles Harbor. They were given a nominal 16-pound treatment with Grade I creosote. These piles were removed in 1924 because of a change in the design of the wharf facility, but it was noted that deterioration caused by *Limnoria* attack was in advanced stages. A new apron wharf was constructed at the same location in the same year (using 16-pound creosoted Douglas fir piles). In 1939, after 15 years service, this wharf suffered a complete collapse, again because of the ravages of *Limnoria.*"

Figure 7—*Limnoria* burrows in untreated pine.

Figure 8—Siphons of Teredine borers.

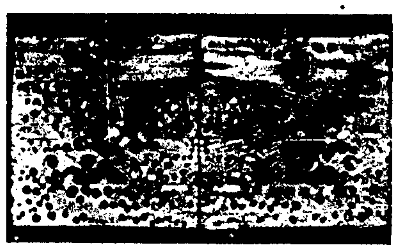

Figure 9—Interior of laminated test block.

Figure 10—Separation of laminations of test block.

When the pier collapsed, shown in Figure 12, a railroad car of scrap steel was deposited at the bottom of the harbor.

Because creosoting does not produce piling of sufficient durability in many harbors, numerous other treatments have been evaluated as marine borer deterrents. Among these are a number of

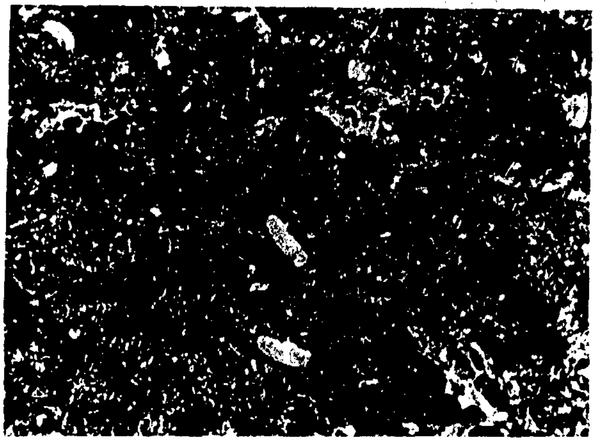

Figure 11—*Limnoria* burrows on creosoted pile.

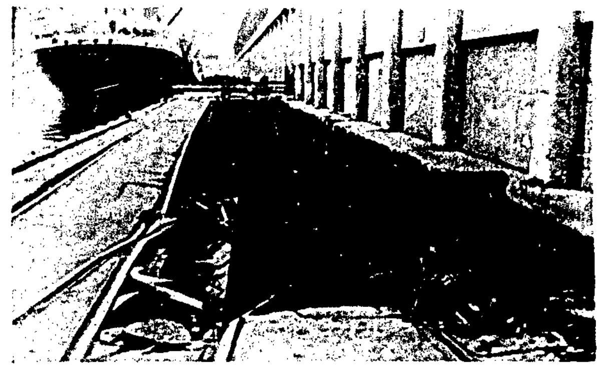

Figure 12—Wharf destroyed by borers after 15 years in Los Angeles Harbor.

copper-containing compounds such as copper naphthenate, copper pentachlorophenate, copper fluoride and copper arsenate. In all instances, where sufficient exposure data are available, these treatments fail after a few years. Impregnation with several plastics has shown some promise. Woods, however, differ widely in their ability to take such treatment. No treatment other than the incorporation of coal tar in creosote has demonstrated a superiority to creosote. In some instances more testing must be done before complete evaluations can be made.

Current Research

Because of the extensive waterfront structures required by the Navy, the Bureau of Yards and Docks has instituted a systematic investigation of the whole marine borer problem. One part of its program is to fractionate creosote and determine the borer resistance of the various fractions. This study is being conducted jointly by the Naval Research Laboratory, Washington, D. C., and the Marine Biology Laboratory of the University of Miami, Miami, Florida. The William F. Clapp Laboratories, Duxbury, Massachusetts, are investigating the distribution of the various species of borers in many harbors throughout the world.

The U. S. Naval Civil Engineering Laboratory of the Bureau of Yards and Docks is engaged in several phases of this program.

First, the alkaloids of greenheart are being investigated. These compounds are toxic to marine borers. The structures of these compounds will be used as a basis for the synthesis of impregnating materials that can be applied to more common woods.

Second, two toxicity screening procedures have been developed using adult *Limnoria tripunctata* and *Teredo diegensis* larvae as the test animals. Although both *Limnoria tripunctata* and *Limnoria quadripunctata* are present in Hueneme harbor, the essentially pure culture of *Limnoria tripunctata* used in the screening tests is obtained from creosoted piles that have been in the harbor for several years.

Third, the effects on these animals of environmental conditions, such as temperature and salinity, are being studied. Attempts are being made to correlate the results of the toxicity tests with physiological functions as another means of developing more potent toxic agents.

Fourth, the factors involved in the retention of chemicals by wood are being studied because an extremely toxic agent is of little value if rapidly leached out of the wood.

Finally, those compounds which merit further study on the basis of the several screening procedures are impregnated into small wooden panels and exposed in Hueneme Harbor and in Pearl Harbor. There have been a number of systems that merited such evaluation. The tests on these materials have not progressed sufficiently to permit an evaluation of these systems at this time.

Ideal Wood Preservation

The properties of an ideal wood preservative for marine use may be summarized as follows:

1. The preservative must be toxic to boring organisms in very small concentrations. When a *Teredo* larva has grown to an animal only one centimeter long, a 3000-fold increase in volume has taken place. Thus, once a teredine borer gets a foothold in a piece of wood and begins to grow, the amount of toxic material required to stop it goes up almost exponentially.

2. The treatment must be resistant to leaching by sea water and must remain in the wood in toxic concentrations for many years.

3. The treating materials must be stable in a marine environment and must not be altered to a less toxic material. Thus, mercuric chloride is very toxic to borers, but the hydrogen sulfide present in almost all harbors would detoxify this substance by converting it to the nontoxic mercuric sulfide.

4. The preservative must penetrate the wood readily and not be filtered by the wood surface.

5. The preservative must not decrease the structural strength of the wood.

6. The preservative must not be corrosive to metal fastenings.

7. The preservative must be inexpensive.

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